Fishery Data Series No. 07-42

Klawock Lake Subsistence Sockeye Salmon Project 2005 Annual Report

by

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and

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July 2007

Alaska Department of Fish and Game **Division of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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July 2007

The Federal Subsistence Board approved the Klawock Lake Sockeye Salmon Stock Assessment Project (Study Number FIS 05-603). The project was funded by the USDA Forest Service, managed by U.S. Fish and Wildlife Service Office of Subsistence Management, and is a cooperative project between the USDA Forest Service (USFS), the Alaska Department of Fish and Game (ADF&G), and the Klawock Cooperative Association (KCA). This annual report partially fulfills contract obligations for Sikes Act Contracts AG-0109-C-05-0003 and AG-0109-C-05-0004. Additional funds for this project were also provided by the Southeast Sustainable Salmon Fund.

The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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This document should be cited as:
Conitz, J. M., and M. A. Cartwright. 2007. Klawock Lake subsistence sockeye salmon project 2005 annual report. Alaska Department of Fish and Game, Fishery Data Series No. 07-42, Anchorage.

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ABSTRACT

Sockeye salmon runs returning to Klawock Lake are an integral part of the history, culture, and contemporary lifestyle of the village of Klawock, and many Klawock residents feel the runs may be smaller than they were in the past. Our project was started in 2001 to address a need for better information about Klawock sockeye runs and improve methods for estimating escapement and subsistence harvest in this system. In 2005, we counted 14,840 sockeye salmon at a weir on the outlet stream, and we verified this count with a mark-recapture estimate of about 13,700 fish (95% confidence interval 12,400–15,300). We also attempted spawning population estimates for each of three main lake tributaries, and they totaled about 10,500 fish (CV=28–40% for the individual estimates). Although less precise, these Jolly-Seber estimates captured at least 70% of total escapement, and provided specific information for each spawning stream. The sockeye escapement in 2005 was nearly identical with the average annual escapement of about 14,800 fish for the five years 2001–2005. However, the subsistence harvest of Klawock Lake sockeye salmon in 2005 was almost a complete failure, with only about 175 fish harvested in an extended season. Therefore the overall run size for 2005, counting both escapement and subsistence harvest, was about 5,000 fish smaller than in 2001–2004, with the entire loss being taken by the subsistence users. Despite the appearance of stability in overall run sizes in 2001–2005, we are concerned about a possible decline in the productive capacity of the lake, evidenced by an apparent increase in smolt age recently. Possible factors affecting sockeye production in Klawock Lake include habitat degradation caused by logging and road building in the watershed, and excessive output of hatchery fry, including both sockeye and coho salmon.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Klawock Lake, Klawock, weir, escapement, mark-recapture, age composition

INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka*) returning to Klawock Lake (Figure 1) have supported a permanent human settlement since pre-historic times (Langdon 1977), as well as the earliest historical commercial fishing and fish processing operations in the area (Moser 1899; Roppel 1982). Present-day residents of Klawock continue to depend on sockeye salmon, harvesting about 7,500 fish annually from nearby waters, including some 4,000–6,000 annually from the Klawock River estuary (Alaska Department of Fish and Game (ADF&G) Division. of Subsistence Community Profile Database 2001; Conitz et al. 2006). Klawock sockeye salmon undoubtedly also contribute to the incidental sockeye harvest in nearby commercial seine fisheries, although quantification by individual stock is not yet feasible.

Commercial fishing began in Klawock Inlet in 1968 (Moser 1899; Roppel 1982). From early commercial harvest statistics, we know that about 35,000–40,000 sockeye salmon were harvested annually in the vicinity of the Klawock River estuary, with high harvests of over 70,000 sockeye salmon in a few of those years (Moser 1899; Rich and Ball 1933). Early commercial fishing practices, such as placing complete barriers across the mouth of the stream, led to very high exploitation rates on sockeye salmon runs, so these early catch statistics were probably a good indicator of relative run sizes. Federal conservation laws implemented in the 1920s moved most fisheries away from the mouths of sockeye streams; as a result, commercial harvests and associated catch statistics included a mixture of stocks and no longer provided a reliable indicator of the Klawock sockeye run in isolation. Beginning in the 1930s and continuing intermittently through the remainder of the century, weirs were used to count or estimate the number of sockeye and other salmon species returning to Klawock Lake to spawn. Probably the most reliable of these estimates were weir counts from 1930 to 1938, showing a mean annual escapement of 31,000 sockeye salmon, with a range of 7,000–65,000 sockeye salmon (Orrell et al. 1963). Between 1968 and 2000, sockeye counts at the Klawock River weir ranged from about 1,000 to 20,000 fish, but the counts are known to be incomplete or unreliable in most years (Lewis and Zadina 2001).

Concerns about sustainability of the resource in the face of high fishing pressure led to early attempts to supplement the wild sockeye stocks with hatchery propagation. The early hatchery released sockeye salmon as sac-fry into the lake with little or no assurance of their survival, nor any way to evaluate it. Given the many serious problems, such as freezing of eggs over winter (Roppel 1982), these supplementation efforts were unlikely to have contributed much to sockeye stocks in this system. The early Klawock hatchery finally closed in 1917 for lack of a qualified hatchery superintendent (Roppel 1982). The modern hatchery facility began operations in 1978 with production of coho and chum salmon, and added sockeye production in 1980 (Lewis and Zadina 2001). Originally operated by the ADF&G Fisheries Rehabilitation, Enhancement, and Development (FRED) Division, the hatchery was transferred to the Prince of Wales Hatchery Association (POWHA) in 1996. Between about 250,000 and 900,000 sockeye fry were released annually between 1996 and 2004, most commonly as emergent fry (Appendix C in POWHA 2005 annual management plan). Until 1999, when POWHA began thermally marking otoliths in hatchery-produced sockeye salmon, the success of sockeye stocking efforts in Klawock Lake had not been scientifically evaluated (Lewis and Zadina 2001). In 2001, researchers at ADF&G began sampling otoliths from sockeye fry and smolt in Klawock Lake for thermal marks, and beginning in 2003, otoliths from adult sockeye salmon returning to the Klawock subsistence fishery and Klawock Lake were also sampled. Very few marked otoliths were found in these samples through 2005, indicating the survival of hatchery-produced sockeye salmon is probably very low (ADF&G Thermal Mark Laboratory Mark Summary Report database,

http://tagotoweb.adfg.state.ak.us/OTO/reports/MarkSummary.aspx).

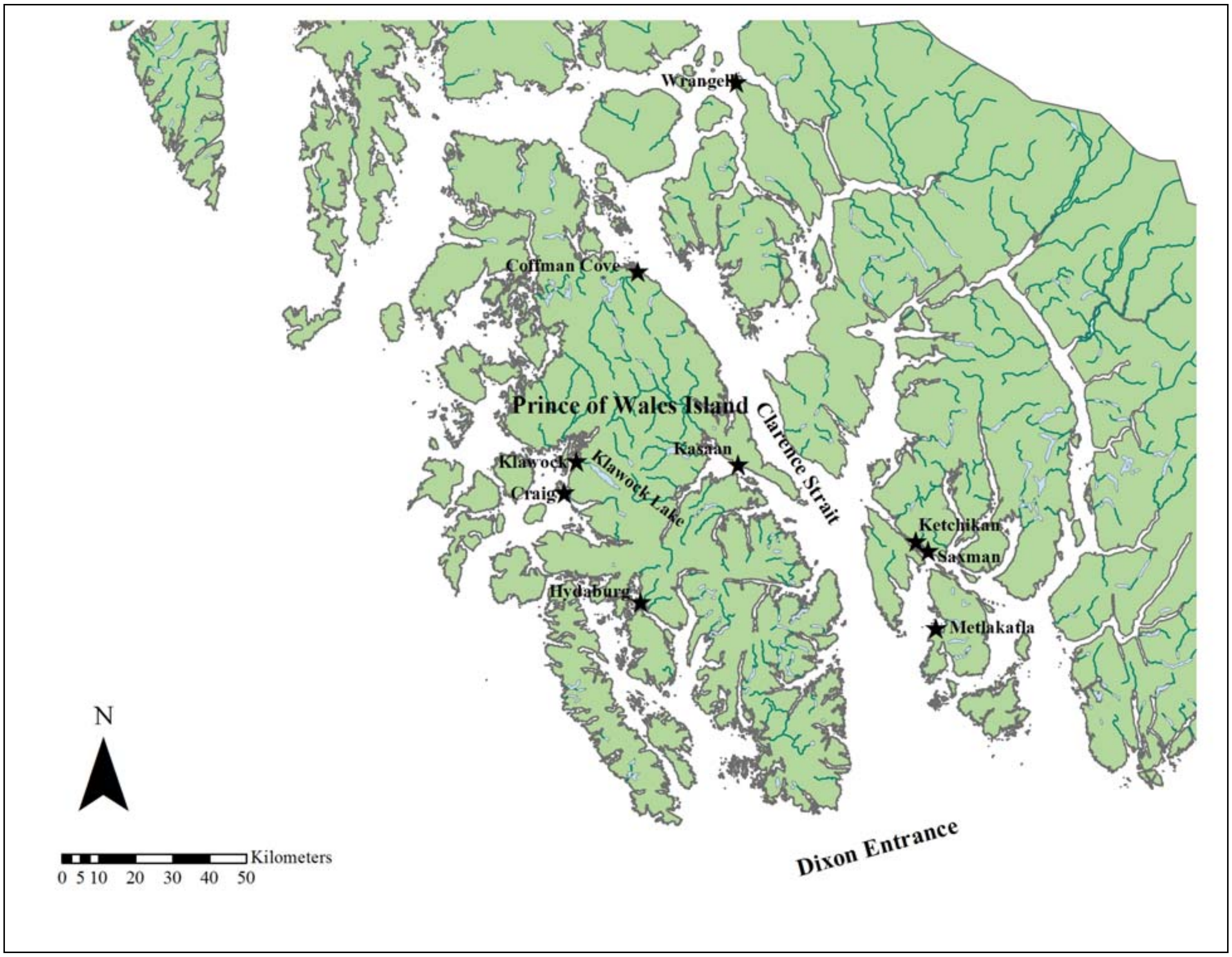

Figure 1.–Geographic location of Klawock Lake, in Southeast Alaska on Prince of Wales Island. The communities of Klawock and Craig, and other towns on and near Prince of Wales Island are shown.

Because of the size and importance of the Klawock subsistence fishery, and ongoing concern in the community over a real or perceived decline in sockeye run sizes, researchers at ADF&G initiated a thorough sockeye stock assessment program in 2001 (Lewis and Cartwright 2002). The researchers began with a series of improvements to the Klawock River weir. Furthermore, because weirs can be subject to flooding and erosion and allow uncounted passage of fish, mark-recapture experiments were used to validate the weir counts (Lewis and Cartwright 2002; Cartwright and Lewis 2004; Cartwright and Conitz 2006). Mark-recapture estimates of escapement were much higher than weir counts in 2001 and 2003, underscoring the necessity of obtaining this mark-recapture-based estimate in addition to the weir count (Lewis and Cartwright 2002; Cartwright and Conitz 2006). A redesigned and reinforced weir structure was put into place in 2004 and the weir count and mark-recapture estimate agreed closely in that year (Conitz et al. 2006).

Recent estimated sockeye escapements in Klawock Lake appear to be remarkably stable, ranging from 12,000 to 21,000 fish in 2001–2004 (Conitz et al. 2006). During those years, a nearly constant level of subsistence harvest was also maintained, estimated between about 4,000 and 7,000 fish (Conitz et al. 2006). The average annual run size (escapement and subsistence harvest) for Klawock Lake in 2001–2004 was about 21,000 fish, comparable to several other Prince of Wales Island sockeye runs such as Salmon Bay and Luck Lakes (Cartwright et al. 2006), Karta River (Organized Village of Kasaan, POWTEC LLC, unpublished report 2005), and Sarkar Lake (ADF&G Division of Commercial Fisheries database, 2005). The apparent stability of Klawock sockeye run sizes in recent years contrasts with sockeye runs to Hetta Lake, formerly one of the largest producers on Prince of Wales Island. The Hetta Lake sockeye run dipped to very low levels in 2002 and 2004, as reflected by subsistence harvests of 1,000 or fewer fish in 2002 and 2004 (Conitz et al. 2007). Nevertheless, sockeye runs to Klawock Lake observed in 2001–2004, like those to Hetta Lake, are clearly much smaller than those documented in historical records (Moser 1899; Rich and Ball 1933; Orrell et al. 1963).

In 2005, we completed the fifth year in an ongoing series of sockeye run size assessments for Klawock Lake. The escapement estimate was obtained by a weir count as in previous years, and validated with a mark-recapture estimate. In addition, we continued as in previous years, to separately estimate sockeye spawning populations in Threemile, Halfmile, and Inlet Creeks. Beginning in 2004, we used individually numbered tags to mark fish sampled in each of these three spawning areas, and used the Jolly-Seber model to estimate each of these populations separately (Conitz et al. 2006). Estimates from this additional mark-recapture study were compared with the weir-based estimates in attempt to determine the feasibility of estimating sockeye escapement in Klawock Lake without a weir, as a less expensive option for continuing studies in the future. Identifying individual salmon with numbered tags also allowed us to study timing of sockeye spawning and movement between spawning areas. For estimates of the subsistence sockeye harvest in Klawock Inlet, we used an on-site “roving-access” survey (Bernard et al. 1998) as in previous years (Lewis and Cartwright 2002; Cartwright and Lewis 2004; Cartwright and Conitz 2006; Conitz et al. 2006). We also continued to sample sockeye spawners for age, sex, and length information, and looked for trends or changes in the age structure of the population.

OBJECTIVES

1. Estimate the subsistence harvest of sockeye salmon from Klawock Lake, so the estimated coefficient of variation was less than 15%.
2. Count the number of salmon through the weir, by species and date, from 1 July to 15 October.
3. Estimate the sockeye escapement into Klawock Lake with mark-recapture methods, marking salmon at the weir and conducting recapture sampling in the major spawning streams, so the estimated coefficient of variation was less than 10%.
4. Estimate the sockeye spawning populations in Threemile, Halfmile, and Inlet Creeks using mark-recapture methods, so the estimated coefficient of variation was less than 15% for the combined estimate.
5. Estimate the age, length, and sex composition of the sockeye salmon in the escapement at Klawock Lake, so the estimated coefficient of variation was less than or equal to 5% for the largest two age classes.

STUDY SITE

The Klawock River system (ADF&G stream number 103-60-047) is located on the west side of Prince of Wales Island (Figure 1), and enters Klawock Inlet at the site of the village of Klawock (lat 55^{o} 32.97'N, long 133^{o} 02.60'W). Klawock Lake has two main basins and numerous tributaries; the four major tributaries provide most of the sockeye spawning habitat in this system. At the head of the lake, Inlet Creek flows into basin B (maximum depth 49 m; Figure 2), draining a total area of 37.6 km^2. Hatchery Creek, Halfmile Creek, and Threemile Creek flow into basin A, the larger and shallower of the two basins (maximum depth 30 m; Figure 2). These major tributaries to basin A drain a total watershed area of 76.1 km^2. Klawock Lake sits at 9.1 m elevation, and has a total surface area of 11.9 km^2, mean depth of 17.7 m, maximum depth of 49.0 m, and volume of 209 x 10^6 m^3 (Figure 2). The lake is dimictic, organically stained, and has a mean euphotic zone depth (EZD) of 4.2 m, based on limnological data collected in 1986–1988 and 2001 (Lewis and Cartwright 2002). Klawock Lake empties into Klawock Inlet via the Klawock River (2.85 km). The Prince of Wales hatchery and the weir are located on the Klawock River approximately 300 m below the lake.

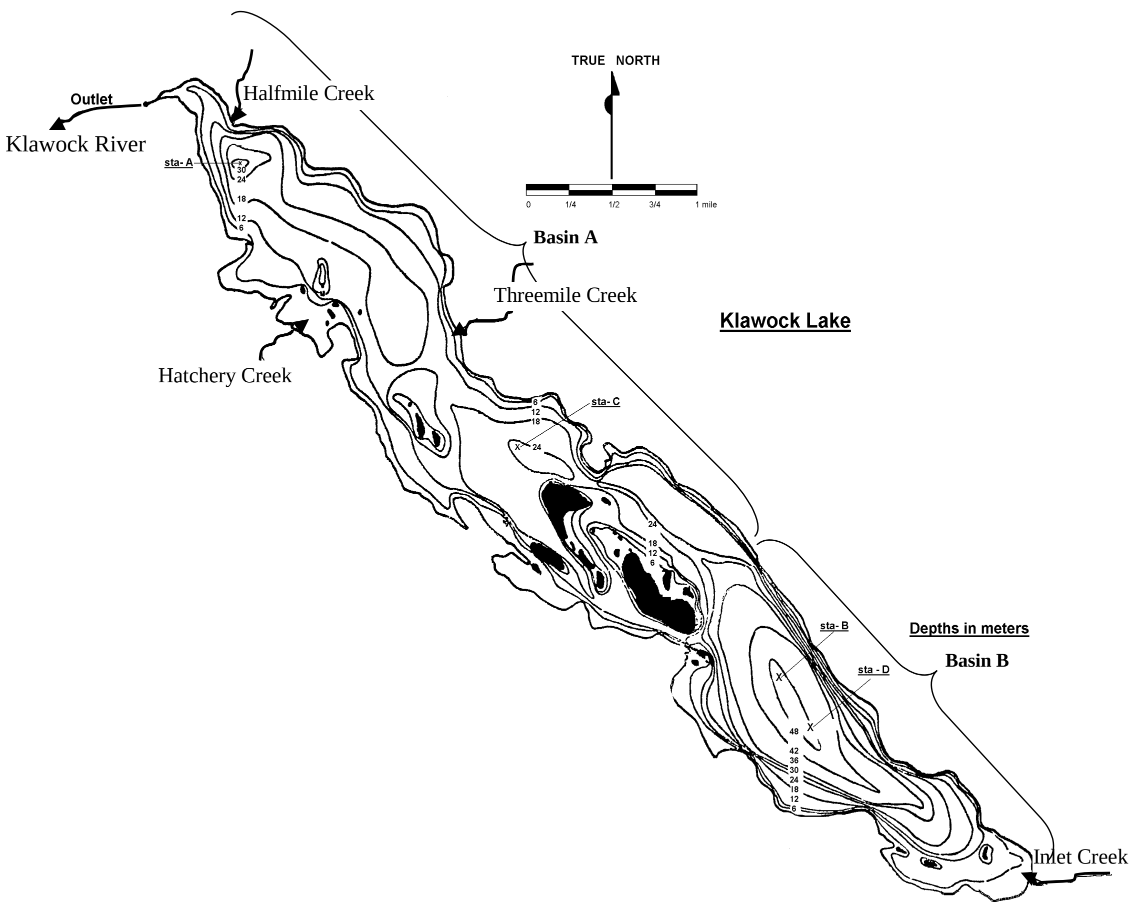

Figure 2.–Bathymetric map of Klawock Lake, showing the two main lake basins, four main inlet streams (Halfmile, Threemile, Inlet, Hatchery), and the Klawock River outlet stream.

In addition to sockeye salmon, native fish species include coho (*O. kisutch*), pink (*O. gorbusha*), and chum (*O. keta*) salmon, steelhead (*O. mykiss*) and cutthroat trout (*Oncorhynchus clarki clarki*), Dolly Varden char (*Salvelinus malma*), threespine stickleback (*Gasterosteus aculeatus*), and cottids (*Cottus* sp.). Mysid shrimp (*Neomysis mercedis*) are also present in the lake. The Klawock Lake zooplankton assemblage has been dominated in recent years by the small copepod *Cyclops* sp. and the small cladoceran *Bosmina* sp., with a relatively much smaller component of the large cladoceran *Daphnia* (Cartwright and Conitz 2006; Conitz et al. 2006).

METHODS

SUBSISTENCE HARVEST ESTIMATE

The subsistence fishery, by regulation, was open from 7 July through 31 July on Monday at 0800 through Friday at 1700 each week. Because of extremely low harvest during the normal opening, the fishery was extended and re-opened from 2 through 5 August. We randomly selected three days out of each week to observe and interview fishers (Table 1). However, the first week had only two legally open fishing days, so sampling was conducted on both days. During the week when the fishery was extended by four days (2–5 August), we randomly selected just two days for sampling (Table 1). We divided each sampling day, from 0600 to 2200 hours, into two shifts, 0600–1400 hours and 1400–2200 hours, with reduced hours on Monday and Friday.

Table 1.–Sampling dates selected randomly in each of the five weeks of the Klawock Inlet subsistence fishery in 2005.

Week	Calendar Dates	Sampling Dates
1	3–9 July	7, 8 July
2	10–16 July	12, 14, 15 July
3	17–23 July	18, 19, 22 July
4	24–30 July	25, 26, 28 July
5	31 July–6 August	3, 5 August

All subsistence fishers used small, hand-pulled seine nets and usually used two boats to deploy a single net. A set was defined as a single net deployment and retrieval. A *boat-party* referred to all the people on one or two boats fishing the same net. The samplers used binoculars and a motorized skiff to monitor the fishery, positioning themselves on the shore or in the skiff where they could see all boat-parties fishing in Klawock Inlet. As a net was being pulled up, the sampler approached the participants to verbally interview them, or the sampler observed the set and recorded the pertinent information. In addition to direct verbal interviews, samplers and fishers used hand signals to communicate the size of the catch. Hand signals or simply visual observation were often used to indicate that zero fish were caught in a set. If the technician received information from hand signals or visual observation, he usually did not obtain a verbal interview. Verbal interviews were usually used when larger numbers of fish were caught in a set. At the conclusion of the interview, the sampler recorded the date, type of interview (hand, verbal, or visual), number of salmon caught by species, time of day, gear, town of residence, and any comments. The sampler assigned a number to each interview. Names of fishers were not recorded to guard the confidentiality of the fishers. Samplers attempted to interview all boat-parties after each set. However, in cases where samplers were unable to interview a boat-party after a set, the sampler recorded this set as a “missed interview.”

We viewed the statistical population to be a collection of "net sets." Sets were organized into a day within a week. Sampling followed a two-stage design: a day within a week was selected at random (first stage) and then a set within a day (second stage) was selected if needed (Bernard et al. 1998; Thompson 1992). In the second stage estimation, the average harvest for the day was assigned to any set recorded as a "missed interview." In the first stage estimation, the average harvest per day, within a week, was expanded to estimate harvest for the days not sampled each week. If the fishery was open for three or fewer days in a week, all days were sampled and no expansion was necessary for days not sampled.

We let h_{ijk} denote the harvest for set *i* on day *j* in week *k*, and m_{jk} denote the number of completed interviews on day *j*, in week *k* (i.e. the total number of sets for which interviews were obtained). Also, M_{jk} denoted the total number of net sets counted on day *j* in week *k* (i.e. the total number of sets observed, including any missed interviews), and d_k denoted the total number of days sampled out of D_k legal fishing days in week *k*. In 2005, the first week had two legal fishing days and the last week had four legal fishing days; all other weeks had five legal fishing days. For a given species, the harvest for week *k* was estimated as,

$$\hat{H}_k = \frac{D_k}{d_k}\sum_{j=1}^{d_k}\frac{M_{jk}}{m_{jk}}\sum_{i=1}^{m_{jk}} h_{ijk} \ ,$$

and the total harvest for the season was estimated as the sum of weekly harvests,

$$\hat{H} = \sum_{k=1}^{5}\hat{H}_k \ .$$

To estimate the variance of $\hat{H}$, we let $\bar{h}_{jk}$ denote the mean harvest per set, on day *j* in week *k*, and $\bar{h}_k$ denote the mean harvest for the week. We then estimated the variance for the estimated harvest in week *k* as,

$$\text{var}(\hat{H}_k) = \frac{D_k}{d_k}\sum_{j=1}^{d_k} M_{jk}^{\ 2}\left(1-\frac{m_{jk}}{M_{jk}}\right)\frac{\sum_{i=1}^{m_{jk}}(h_{ijk}-\bar{h}_{jk})^2}{m_{jk}(m_{jk}-1)} + D_k^{\ 2}(1-\frac{d_k}{D_k})\frac{\sum_{j=1}^{d_k}(\bar{h}_{jk}-\bar{h}_k)^2}{d_k(d_k-1)}$$

(Thompson 1992, p. 129).

The overall variance for the season was estimated by summing the five weekly variance estimates, $\text{var}(\hat{H}) = \sum_{k=1}^{5}\text{var}(\hat{H}_k)$, and the standard error was estimated by taking the square root of the seasonal variance estimate.

SOCKEYE ESCAPEMENT ESTIMATES

Weir Counts and Mark-Recapture Estimate

We operated the Klawock River weir from 5 July to 4 November 2005. The permanent weir structure was rebuilt in 2004 (Conitz et al. 2006), with removable pickets placed in the weir seasonally to channel migrating salmon into the hatchery raceway. Also in 2005, we added a 2.5m × 1.2m rectangular aluminum frame and picket trap, adjoining the weir in mid-channel, to facilitate passage of salmon through the deeper part of the channel during periods of low water. Fish migrating upstream were either diverted at the weir into the hatchery's raceway, or allowed to pass into the trap through two open pickets; each station had a sampling platform where fish were identified by species, counted, and passed upstream. Jack sockeye salmon, defined in the Klawock system as male sockeye salmon under 420 mm, were noted as jacks in the daily count.

To test the accuracy of the weir count, we also estimated escapement using a stratified, closed-population mark-recapture study (Arnason et al. 1996). The crew marked sockeye salmon as they passed them through the weir with an adipose fin clip and a uniquely-numbered t-bar tag, at an attempted rate of twenty percent of the weekly number counted. The primary mark was an adipose clip, indicating presence of a tag; this dual marking system allowed the crew to monitor for tag loss. Following the season, tag numbers were used to assign all tagged fish into marking strata of one week each.

Recapture sampling was conducted on the spawning grounds at intervals approximately one week apart, throughout the spawning season. At least six sampling events were attempted in Threemile Creek, Inlet Creek, and Halfmile Creek (Figure 2). Mark-recapture sampling was not attempted in Hatchery Creek because previous years' surveys indicated that spawners in that stream made up a very small proportion of the total spawning population in Klawock Lake (Cartwright and Conitz 2006). Fish were sampled with small beach seines as they schooled at the mouth of the stream, and with dip nets in the channel of each stream. All unmarked fish in these samples were tagged and given an opercular punch to identify the sampling event in which the fish was caught. Tag numbers were recorded for all fish caught in the sample, whether newly tagged or tagged in a previous event. Fish in these samples were only counted on the first recapture event in which they were encountered.

The two-sample Petersen model provides a simple method for estimating population size, based on the number of animals marked in an initial or first sample, the number of animals subsequently sampled for marks in a second sample, and the number of marks recovered in the second sample (Seber 1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models extend the two-sample Petersen method over two or more sampling events in both the marking (first) and mark-recovery (second) samples. Stratified models are widely used for estimating escapement of salmonids as they migrate into their spawning streams (Arnason et al. 1996). Spawning migrations may last for a month or more, during which time there can be substantial variation in biological parameters such as mortality rates. A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). Briefly stated, the three assumptions of equal probability of capture required by the Petersen model are: 1) all fish have an equal probability of capture in the first sample (marking), 2) all fish have an equal probability of capture in the second sample (mark-recovery), and 3) fish mix completely between the first and second sample. Generally, if one or more of these assumptions is met, the marking and recovery strata can be pooled, thereby providing the most precise estimate. However, if none of the assumptions are met, the pooled estimate can be badly biased (Arnason et al. 1996).

We used the Stratified Population Analysis System (SPAS) software as an aid in analyzing and interpreting our mark-recapture results (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). SPAS calculates Darroch and pooled Petersen estimates, and provides two goodness-of-fit tests to compare observed and expected capture probabilities in the marking (first) and mark-recovery (second) samples (Arnason et al. 1996). This program also provides associated standard errors of the estimates. The test of the assumption of complete mixing is incorporated into the test for equal probability of capture in the second sample. We considered a test statistic with p-value ≤ 0.05 as "significant."

We looked at sample sizes and capture probabilities in each marking and mark-recovery stratum, and considered any natural events such as flooding or failures of our technicians to follow the sampling design. We then checked the Darroch estimate for possible problems, such as a failure of the SPAS program to converge to a solution, or estimates much larger or smaller than the pooled Petersen estimate. Followed the guidelines and suggestions in Arnason et al. (1996) we searched for a pooling scheme that led to the fewest number of strata with non-significant test statistics and an absence of other diagnostic problems.

We used a parametric bootstrap procedure to estimate the standard error and construct the 95% confidence interval for pooled Petersen escapement estimate. We assumed that the number of marked fish recaptured in the second sample, m_2, follows a hypergeometric probability distribution. Then we used the number of fish marked in the first sample, n_1, the number of fish caught in the second sample, n_2, and the Petersen estimate of escapement, $\hat{N}$, to generate 5,000 simulated recapture numbers based on the hypergeometric probability density function, $f(m_2 | n_1, n_2, \hat{N})$. From the bootstrap values of m_2, we derived 5,000 Petersen escapement estimates, then calculated the standard error of these estimates and used the 0.025 and 0.975 quantiles to form the 95% confidence interval.

The 95% confidence interval bounds were used to judge the accuracy of the weir count. If the weir count fell within the 95% confidence interval bounds, it was considered accurate. If the weir count was below the lower 95% confidence interval bound, we considered the possibility that the weir count was inaccurate and some fish escaped through undetected. In that case, the mark-recapture estimate, if unbiased, could be more accurate. A weir count above the 95% confidence interval bounds could only indicate the mark-recapture estimate was inaccurate, because the weir count, if free of counting errors, would always represent a minimum number of fish in the lake.

Spawning Grounds Mark-Recapture Study

The weir count and weir-based mark-recapture estimate applied to the total population of sockeye salmon that entered Klawock Lake to spawn. We also conducted a second, independent mark-recapture study to separately estimate the number of sockeye salmon in each of the three main spawning tributaries of Klawock Lake: Threemile, Inlet, and Halfmile Creeks (Figure 2). Again, Hatchery Creek was excluded because its sockeye spawning population appears to be very small. We calculated these spawning population estimates using the Jolly-Seber model for open populations (Pollock et al. 1990), with an adjustment for spawning salmon populations (Schwarz et al. 1993). These estimates were intended to provide additional information about spawning habitat availability and use in Klawock Lake. Furthermore, we compared these stream-based estimates with the weir count and weir-based estimate, to see if they would approximate the weir estimates. If so, a spawning grounds mark-recapture study in Threemile, Inlet, and Halfmile Creeks could be used in the future to estimate total sockeye escapement in Klawock Lake at less cost than operating the weir.

The field crew used a beach seine to capture sockeye spawners at the stream mouths, and a dipnets to capture fish in the stream channels. Sampling began as soon as sockeye salmon moved into the spawning areas and continued at approximately weekly intervals until the number of available spawners declined and it was apparent that few or no new fish were entering the spawning areas. All unmarked fish were tagged and all fish were marked with an opercular punch to identify the sampling event in which they were caught. A crew member recorded tag numbers of all newly captured and recaptured fish, along with sampling date and location. Fish that had already been tagged at the weir were treated as if they were tagged on the first sampling event in which they were encountered on the spawning grounds. At the end of the season, we constructed an individual capture history for each fish, denoting a sampling event in which the fish was captured with a "1" and a sampling event in which the fish was not captured with a "0" (Pollock et al. 1990).

Data Analysis

The Jolly-Seber model extends the Schnabel method (Seber 1982, p. 130) to open populations. Population size is estimated at the time of each sample, and the number of new animals entering the population is estimated between sampling events, for s sampling events. In using this model we must make the following assumptions:

1. Every fish present in the population at time of the i^{th} sampling event (i=1, 2, …, s) has the same probability of capture (p_i).
2. Every fish (marked and unmarked) present in the population immediately after the i^{th} sampling event has the same probability of survival (ϕ_i) until the $(i+1)^{th}$ sampling event (i = 1, 2,…, s-1).
3. Marks are not lost or overlooked.
4. Sampling time is negligible.

We designated the following parameters:

N = size of "super-population," or escapement;

M_i = number of marked fish in the population at time of the i^{th} sampling event (i=1, 2, …, s; M_1 = 0);

N_i = total number of fish in the population at time of the i^{th} sampling event (i=1, 2, …, s; N_1=B_0);

B_i= total number of new fish entering the population before the first event and between the i^{th} event and $(i+1)^{th}$ event, and still in the population at time of the $(i+1)^{th}$ event (i=1, …, s-1);

B_0 = the number of fish that entered the population before the first event and are still alive at the time of the first event; and

ϕ_i = survival probability for all fish between the i^{th} event and $(i+1)^{th}$ event (i=1, 2, …, s-1).

We also designated the following statistics:

m_i = number of marked fish captured in the i^{th} event (i=1, 2, …, s);

u_i = number of unmarked fish captured in the i^{th} event (i=1, 2, …, s);

$n_i = m_i + u_i$, total number of fish captured in the i^{th} event (i=1, 2, …, s);

R_i = number of the n_i fish that are released after the i^{th} event (i=1, 2, …, s-1; this may not be all of n_i fish due to losses on capture);

r_i = number of R_i fish released at i and captured again (i=1, 2, …, s-1); and

z_i = number of fish captured before i, not captured at i, and captured again later (i=1,2, …, s-1).

Seber (1982 p. 204) recommended the following unbiased estimators:

$$\hat{M}_i = m_i + \frac{(R_i + 1)z_i}{r_i + 1}, \text{and } \hat{M}_1 = 0;$$

$$\hat{N}_i = \frac{(n_i + 1)\hat{M}_i}{m_i + 1};$$

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i};$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i).$$

Seber also recommended that m_i and r_i should be greater than 10 for satisfactory performance of these bias-adjusted estimators.

We assumed the interval between the last (s^{th}) sampling event, and the next-to-last ($(s\text{-}1)^{\text{th}}$) sampling event was so short that the number of fish entering the population during this interval was negligible. Furthermore, we assumed that sampling extended to a time when immigration had ended, and the number of fish entering the population was negligible. In the Jolly-Seber model, the total population is usually estimated as the sum of $\hat{B}_i$, the estimated numbers of fish that entered the population between sampling events. However, $\hat{B}_i$ are estimates of the number of fish that entered the population after sampling event i and were alive at sampling event i+1. These estimates exclude those fish in the escapement that entered after sampling event i but died before sampling event i+1. Consequently, the sum of the Jolly-Seber estimates of B_i would underestimate the spawning recruitment, except when all fish are known to survive from their entry to the next sampling event. To account for those fish that entered the system after sampling event i, but died before sampling event i+1, we adjusted $\hat{B}_i$ before summing (Schwarz et al. 1993). Let B_i^* denote the total number of new fish entering the population between sampling events (including those that died before the next sampling event). When recruitment and mortality are assumed to occur uniformly between sampling events, the maximum likelihood estimator for B_i^* is,

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}.$$

$\hat{B}_0$, $\hat{B}_1$, and $\hat{B}_{s-1}$ are confounded parameters and cannot be estimated without further assumptions (Schwarz et al. 1993). However, we assumed recruitment had virtually ended before the last sampling event, so we set $\hat{B}_{s-1}$ to zero. The number of fish alive in the population at the second sampling event, N_2, was estimated as,

$$\hat{N}_2 = \hat{B}_0\phi_1 + \hat{B}_1.$$

So a reasonable estimate (Schwarz et al. 1993) of the number of fish that entered the system before the first sampling event and between the first and second sampling events, including those that entered the system and died before and between these sampling events, is,

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}.$$

We then estimated the super-population, or total escapement, as

$$\hat{N} = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{k-1} \hat{B}_i^* .$$

We used a non-parametric bootstrap technique to estimate variance and form a confidence interval for *N*. A computer program to produce these estimates, written in S-Plus (Insightful Corp. 2001), is available from X. Zhang, ADF&G Division of Commercial Fisheries (Xinxian_Zhang@fishgame.state.ak.us). The procedure works by resampling the observed experimental data to create a series of "pseudo-experiments," according to the following algorithm.

1. Analyze observed data using the Jolly-Seber method and Schwarz's adjustment described above to obtain the $\hat{N}$.
2. Sample with replacement from the observed *n* capture histories to generate a bootstrap sample of the same size *n*; analyze the bootstrap sample exactly as if it were the observed sample.
3. Repeat step (2) for 1,000 bootstrap samples to have 1,000 estimates of *N* from these bootstrap samples.
4. Calculate variance and standard error for N^* from the 1,000 bootstrap estimates of *N*.
5. Find the 95% confidence interval by taking the 0.025 and 0.975 quantiles of the 1,000 bootstrap estimates of *N*.

Because the three main spawning streams are well-separated from each other, we assumed that sockeye spawners did not migrate between them after they started entering the streams. We tested that assumption in 2004 by examining capture histories by location, and found evidence that very few fish move between these streams during the spawning period (Conitz et al. 2006). We did not sample all possible sockeye spawning locations in Klawock Lake, most notably Hatchery Creek. Therefore the sum of spawning population estimates for the three major spawning tributaries was expected to be somewhat less than the actual spawning population size for the whole lake system.

Adult Population Age and Size Distribution

About 600 adult sockeye salmon were sampled for length, sex, and scales (for age determination) at the Klawock Lake weir, primarily to estimate the age structure of the population. Fish were selected systematically to prevent selection bias. Weekly target sample sizes were determined, from previous years' run timing data, roughly in proportion to average weekly escapement. Length of each fish was measured from mid eye to tail fork, to the nearest millimeter (mm). Sex of the fish was decided by length and shape of the kype or jaw. Three scales were taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes a five-year-old fish with one freshwater and three ocean years; Koo 1962). The standard error of the proportion in each age class was estimated using standard statistical techniques and assuming a binominal distribution (e.g. Thompson 1992). We expected that this binomial assumption would adequately approximate the standard error, even though we used a systematic sample rather than a random sample.

RESULTS

SUBSISTENCE HARVEST ESTIMATE

The Klawock subsistence fishery was observed for 13 out of the 21 days it was open for sockeye harvest in 2005 (Table 2). During these sampling days, 123 sets were observed and catch information was obtained for 112 of these sets (Table 3). Expanding the sockeye harvest reported in the interviews to account for eleven missed interviews and eight days not sampled, we estimated a total of 175 sockeye salmon (CV= 20%; 95% confidence interval 110–240) were harvested in 2005. Sockeye harvest was very low throughout the season, in comparison with previous years (e.g. Conitz et al. 2006). The highest weekly harvest was just 84 sockeye salmon, estimated for the fourth week of the season (Table 3), and comprising nearly half the total season's harvest.

Table 2.–Reported and estimated daily subsistence harvest for only those days sampled in the two-stage harvest survey of the Klawock Inlet subsistence fishery in 2005. Estimates are not shown for days of the week not sampled. During each day of the survey, the crew observed the entire fishing area and counted all net sets made during that day. At the end of most sets, they interviewed the fishers to determine total sockeye harvest. If interviews were missed for some sets in a day, the total daily harvest was estimated by dividing the average harvest per interviewed set that day by the proportion of all sets that were interviewed.

				Daily sockeye harvest for days in the survey only		
Week	Date	Sets counted	Sets interviewed	Reported in interviews	Expanded for missed interviews	Std error
1	7 Jul	0	0	0	0	0
	8 Jul	3	3	3	3	0
2	12 Jul	1	1	0	0	0
	14 Jul	4	4	4	4	0
	15 Jul	2	2	1	1	0
3	18 Jul	16	16	8	8	0
	19 Jul	22	22	20	20	0
	22 Jul	12	10	5	6	2
4	25 Jul	24	19	26	33	9
	26 Jul	19	17	9	10	2
	28 Jul	6	4	5	8	3
5	3 Aug	0	0	0	0	0
	4 Aug	14	14	9	9	0

Table 3.–Summary of weekly estimates of subsistence sockeye effort and harvest in the Klawock Inlet fishery, 2005.

		Number of sets		Expanded weekly estimates	
Week	**Dates**	**Counted**	**Interviewed**	**Sockeye harvest**	**Std error**
1	7–8 July	3	3	3	0
2	11–15 July	7	7	8	5
3	18–22 July	50	48	57	14
4	25–29 July	49	40	84	28
5	2–5 Aug	14	14	23	13
Total		123	112	175	35

SOCKEYE ESCAPEMENT ESTIMATES

Weir Counts and Mark-Recapture Estimate

Sockeye, coho, pink, and chum salmon, Dolly Varden char, and rainbow and cutthroat trout were counted through the Klawock weir between 5 July and 4 November, 2005 (Table 4; Appendix A). Of the 14,840 sockeye salmon counted through the Klawock weir, 2,363 precocious males, or jacks, were identified by the weir crew. By the end of the subsistence sockeye fishery on 5 August, a cumulative total of 3,183 sockeye salmon, or about 21% of total escapement, had passed the weir. Fifty percent of the total sockeye escapement had entered Klawock Lake through the weir by 18 August, and 99% of the escapement was counted through the weir by 28 September. The single highest daily count occurred on 31 July, with 788 sockeye salmon passing the weir. Other peak sockeye escapement days were clustered between 14 and 19 August, and two somewhat smaller peaks occurred on 7 and 18 September (Appendix A).

Table 4.–Summary of fish counts at the Klawock Lake weir in 2005. Counts of Dolly Varden char and trout species are incomplete because the weir spacing allowed smaller individuals to pass directly through, and weir operation was not timed for their migrations. Coho salmon counts include only those fish not retained by the Prince of Wales Hatchery for cost recovery or broodstock. Chum salmon counts do not represent escapement because most chum salmon spawn below the weir and do not enter the lake.

Sockeye salmon	**Number passed**
Full-size adults	12,477
Jacks (males less than 420 mm)	2,363
All sockeye salmon	14,840
Coho salmon	
Full-size adults	3,721
Jacks	2,190
All coho salmon	5,911
Other species	
Pink salmon	199,935
Chum salmon	207
Dolly Varden char	427
Rainbow and cutthroat trout	90

The crew marked and tagged a total of 2,467 sockeye salmon at the weir between 11 July and 12 September (Table 5; Appendix A). The marking rate at the weir varied widely through the season, from only 0.04 during the week of 17 July to a high of 0.58 during the week of 7 August. Although over 1,000 sockeye salmon were passed through the weir after 17 September, no more fish were marked after 12 September, and mark-recapture sampling ended only a few days after marking ended at the weir. Mark-recapture sampling was conducted between 17 August and 23 September at Threemile, Inlet, and Halfmile Creeks. The recapture rate on marks applied at the weir during the first half of the season (through 13 August) was 0.13–0.15, declining to 0.06–0.10 on marks applied at the weir after 13 August. A slightly higher proportion of fish sampled at Inlet Creek was marked than at the other two sampling locations, Threemile and Halfmile Creeks. The overall proportion of marked fish in the mark-recapture samples was about 0.18, comparable to the overall proportion (0.17) marked at the weir (Table 5).

Table 5.–Numbers of sockeye salmon passed and marked during each week between 10 July and 17 September at the Klawock weir; numbers and proportions of marks recovered, and total numbers sampled between 17 August and 23 September on the spawning grounds in Klawock Lake, 2005.

				Number marks recaptured by stream and marking stratum			**All recaptures, by marking stratum**	
Marking stratum (week)	**Sockeye count at weir**	**Number marked**	**Proportion marked**	**Threemile**	**Inlet**	**Halfmile**	**Number recaptured**	**Proportion recaptured**
Before 10 Jul	36	0	-	-	-	-	-	-
10–16 Jul	102	35	0.34	5	0	0	5	0.14
17–23 Jul	226	8	0.04	1	0	0	1	0.13
24–30 Jul	1,355	110	0.08	16	1	0	17	0.15
31 Jul–6 Aug	1,704	198	0.12	20	7	3	30	0.15
7–13 Aug	1,213	698	0.58	62	28	10	100	0.14
14–20 Aug	3,628	726	0.20	59	5	6	70	0.10
21–27 Aug	1,307	99	0.08	7	1	0	8	0.08
28 Aug–3 Sep	1,356	271	0.20	16	0	2	18	0.07
4–10 Sep	1,665	270	0.16	12	5	2	19	0.07
11–17 Sep	1,090	52	0.05	3	0	0	3	0.06
After 17 Sep	1,158	0	-	-	-	-	-	-
Total	14,840	2,467	0.17	201	47	23	271	
Total sampled for marks, by stream				1,153	216	138	**All streams**	1,507
Proportion with marks in sample				0.17	0.22	0.17	**Mean**	0.18

Analysis of the fully stratified Klawock Lake mark-recapture data in SPAS failed to show evidence of serious violations of basic mark-recapture assumptions, with one significant and one non-significant goodness-of-fit test result (Table 6). A Darroch estimate could not be produced with the fully-stratified data set (10 weeks marking and three recapture locations, as shown in Table 5). Therefore, a pooled Petersen estimate of 13,700 fish (CV=5%; 95% confidence interval 12,400–15,200 fish) was used, which was not significantly different than the actual weir count of 14,840 fish, and thus validated the weir count in 2005.

Table 6.–Results of goodness-of-fit tests in SPAS to detect possible violations of mark-recapture assumptions of equal capture probabilities and equal mixing between first (marking) and second (mark-recovery) samples for Klawock Lake sockeye escapement estimate in 2005.

Test name	Assumptions tested[a]	X^2 value	Degrees of freedom	*p*-value
Complete Mixing	2 and 3	27.31	9	**0.001**
Equal Proportions	1	2.49	2	0.288

[a] Mark-recapture assumptions:
1. All fish have an equal probability of capture during the marking phase, or
2. All fish have an equal probability of capture during the recovery phase, or
3. Marked and unmarked fish mix completely between the marking and recovery phase.

Spawning Grounds Mark-Recapture Study

Independent mark-recapture studies were conducted at Threemile Creek, Inlet Creek, and Halfmile Creek during the spawning period in 2005. Sampling began as soon as spawners could be captured at the mouth of each stream, and ended when most of the spawners had died in each stream. At Threemile Creek, 1,145 sockeye salmon were sampled and tagged (Table 7), during eight mark-recapture events between four and six days apart (23, 26, and 30 August; 2, 6, 12, 16, and 21 September). Only about 5% of fish tagged in these events were recaptured. Fewer fish were recaptured in the event immediately following initial tagging than in later events, indicating some spawners had a residence time in Threemile Creek of at least eight to ten days. The incidence of lost tags among recaptured fish was negligible (two out of 63 recaptures, or 3%). Likewise, only one incidence of straying, from Threemile to Halfmile Creek, was noted. The Jolly-Seber estimate of the total spawning population in Threemile Creek was about 10,000 fish (CV=28%; 95% confidence interval 7,000–19,000).

Table 7.–Summary of capture-recapture histories of sockeye salmon sampled on at spawning grounds at Three-Mile Creek in Klawock Lake, 2005. Capture histories have one digit for each of eight sampling events, in chronological order: a "1" indicates sampling events in which the fish was caught, and a "0" indicates sampling events in which the fish was not caught. The number of fish with each observed capture history is shown.

Threemile Creek		
Capture-recapture category	**Capture history**	**Number of fish**
Captured only once; tagged and released	10000000	76
	01000000	120
	00100000	123
	00010000	169
	00001000	61
	00000100	103
	00000010	230
	00000001	201
	Subtotal	**1083**
Tagged and released; recaptured and released on next event	11000000	1
	01100000	1
	00110000	2
	00011000	3

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Capture-recapture category	Threemile Creek Capture history	Number of fish
	00001100	5
	00000110	1
	00000011	10
	Subtotal	**23**
Tagged and released; not recaptured on next event, but recaptured and released on a later event	10100000	1
	10010000	2
	10001000	1
	10000010	2
	01010000	4
	01001000	1
	01000010	2
	01000001	1
	00101000	1
	00100100	1
	00100010	3
	00100001	4
	00010010	5
	00010001	4
	00001010	1
	00001001	2
	Subtotal	**35**
Tagged and released; recaptured and released more than once	10010100	1
	01000011	1
	00101100	1
	00100110	1
	Subtotal	**4**
Total sampled		**1,145**

At Inlet Creek and Halfmile Creek, 216 and 139 sockeye salmon, respectively, were sampled and tagged (Table 8) over the course of five sampling events at each stream (25 August; 1, 9, 15, 23 September at Inlet Creek, and one day earlier at Halfmile Creek). Among the fish tagged at Inlet Creek, so few recaptures were obtained that a valid Jolly-Seber estimate could not be produced. At Halfmile Creek, very few fish were available for sampling, especially on the first few sampling events. Because the samples were so small, data from the first three sampling events were combined, leaving only three sampling events contributing to the Jolly-Seber estimate. No tag loss or straying was observed among recaptures in either stream. Our estimate for spawning escapement in Halfmile Creek was just 170 fish, with very low precision (CV=40%; 95% confidence interval 80–340).

Table 8.–Summaries of capture-recapture histories of sockeye salmon sampled on the spawning grounds at Inlet Creek and Halfmile Creek in Klawock Lake, 2005. Capture histories have one digit for each sampling event, in chronological order: a "1" indicates sampling events in which the fish was caught, and a "0" indicates sampling events in which the fish was not caught. The number of fish with each observed capture history is shown.

	Inlet Creek	
Capture-recapture category	**Capture history**	**Number of fish**
Captured once, and released	10000	8
	01000	29
	00100	71
	00010	66
	00001	39
Subtotal		**213**
Captured once,	00110	2
then recaptured at next event	00011	1
Subtotal		**3**
Total sampled		**216**
	Halfmile Creek	
Capture-recapture category	**Capture history**	**Number of fish**
Captured once, and released	10000	1
	01000	1
	00100	7
	00010	49
	00001	65
Subtotal		**123**
Captured once,	01010	2
then recaptured at next event	00110	6
	00101	2
	00011	6
Subtotal		**16**
Total sampled		**139**

If we assume a combined estimate of about 500 sockeye spawners in Inlet Creek and Halfmile Creek, the sum of the escapement estimates for Threemile, Inlet, and Halfmile Creeks was about 10,500 fish. Because of the large amount of uncertainty in these estimates, we could not conclude this sum was statistically different from the pooled Petersen population estimate or the weir count of about 14,000 fish.

Adult Population Age and Size Distribution

Sockeye salmon were sampled roughly in proportion to weekly escapement at the Klawock River weir between 10 July and 20 October 2005, and a total sample of 534 ageable scales was obtained (Table 9). Five-year-old sockeye salmon returning from brood year 2000 dominated the 2005 escapement, with age-2.2 fish comprising an estimated 37.6% and age-1.3 fish comprising an estimated 28.7% of total escapement. In contrast, four-year-old sockeye salmon returning from brood year 2001 comprised a much smaller percentage of the 2005 escapement, about 18% in total, of which over 5% were age-2.1 jacks. An estimated 12.5% of the 2005 escapement was age-1.1 sockeye jacks (brood year 2002); together, both age classes of jacks made up an estimated 17.6% of escapement. Six-year-old fish of several age classes returning from brood year 1999 (age-1.4, -2.3, and -3.2) represented a small percentage of the escapement. Overall, the age composition estimates indicated that only slightly more than half the sockeye salmon in the 2005 escapement were fish with one freshwater year (age 1.-). The estimated number of age-1.1 and -2.1 jacks in Table 9 was higher than the sockeye jack count at the weir (Table 4), probably because many Klawock Lake sockeye jacks are large, and thus difficult to distinguish visually from full adults.

Table 9.–Estimated age and sex composition of the Klawock Lake sockeye escapement in 2005. The percentage in each age-sex group was estimated from the number of sampled fish in each category. The estimated number of fish in each age class in the 2005 escapement, based on the total weir count, is also shown.

Brood year	**2002**	**2001**	**2000**	**1999**	**2001**	**2000**	**1999**	**1999**	
Age	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**3.2**	**All ages**
Male									
Sample size	67	39	65	1	27	79	9	0	287
Percent of total	12.5%	7.3%	12.2%	0.2%	5.1%	14.8%	1.7%	0%	53.7%
Std error (%)	1.4%	1.1%	1.4%	0.2%	0.9%	1.5%	0.6%	-	2.2%
Female									
Sample size	-	30	88	0	-	122	6	1	247
Percent of total		5.6%	16.5%	0%		22.8%	1.1%	0.2%	46.3%
Std error (%)		1.0%	1.6%	-		1.8%	0.5%	0.2%	2.2%
All Fish									
Sample size	67	69	153	1	27	201	15	1	534
Percent of total	12.5%	12.9%	28.7%	0.2%	5.1%	37.6%	2.8%	0.2%	100.0%
Std error (%)	1.4%	1.5%	2.0%	0.2%	0.9%	2.1%	0.7%	0.2%	0.0%
Est. escapement by age class	1,862	1,918	4,252	28	750	5,586	417	28	14,840

Individually and on average, the largest sockeye salmon in the 2005 escapement were six-year-old fish (age-1.4 and age-2.3), with the exception of one age-3.2 female that was much shorter (Table 10). Among five-year-old fish, those with one freshwater year and three marine years (age-1.3) were substantially larger than those with two freshwater and two marine years (age-2.2), but the latter group had a somewhat higher proportion of females. As expected, an extra year of freshwater growth contributed little to overall size differences, whereas fish with an extra year at sea were substantially larger.

Table 10.–Mean fork length (in millimeters) of sockeye salmon, by age-sex group, in the Klawock Lake escapement, estimated from fish sampled between 11 July and 20 October, 2005.

Brood year	**2002**	**2001**	**2000**	**1999**	**2001**	**2000**	**1999**	**1999**
Age	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**3.2**
Male								
Sample size	67	39	65	1	27	79	9	0
Mean length (mm)	380	501	564	575	387	504	575	-
Std error	3	6	3	0	5	3	6	

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Brood year	2002	2001	2000	1999	2001	2000	1999	1999
Age	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**3.2**
Female								
Sample size	-	30	88	0	-	122	6	1
Mean length (mm)		496	548	-		500	558	502
Std error		4	2			2	9	0
All Fish								
Sample size	67	69	153	1	27	201	15	1
Mean length (mm)	380	499	554	575	387	502	568	502
Std error	3	4	2	0	5	2	6	0

Weekly estimates of escapement by age class showed a slight tendency towards age classes with one freshwater year (age-1.1 jacks, -1.2, and -1.3) returning earlier in the season, and a stronger tendency towards age-2.2 fish returning later in the season (Table 11). However, the estimated proportions were based on weekly samples of fewer than 20 fish at the beginning and end of the run, and may not be very meaningful.

Table 11.–Estimated weekly age composition of the sockeye escapement into Klawock Lake, from 10 July to 22 October, 2005. Percentages in each age class were estimated for each week from scale samples taken in that week. Although fish were passed through the weir before 10 July and after 22 October, scale samples were not taken in those weeks.

Week beginning	Percentage of fish in weekly escapement by age class								Sample size	Weir count
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.2		
10 Jul	17%	26%	35%	4%	4%	0%	13%	0%	23	102
17 Jul	20%	40%	40%	0%	0%	0%	0%	0%	5	226
24 Jul	9%	23%	48%	0%	3%	11%	6%	0%	65	1,355
31 Jul	28%	21%	30%	0%	9%	10%	2%	0%	94	1,704
7 Aug	30%	0%	0%	0%	30%	40%	0%	0%	10	1,213
14 Aug	13%	10%	33%	0%	4%	38%	2%	0%	148	3,628
21 Aug	10%	10%	28%	0%	0%	48%	3%	3%	39	1,307
28 Aug	9%	11%	24%	0%	7%	47%	2%	0%	45	1,356
4 Sep	8%	0%	26%	0%	5%	62%	0%	0%	39	1,665
11 Sep	3%	0%	10%	0%	3%	79%	3%	0%	29	1,090
18 Sep	0%	0%	7%	0%	0%	93%	0%	0%	14	842
25 Sep	0%	0%	17%	0%	0%	83%	0%	0%	18	215
2 Oct	0%	50%	0%	0%	0%	50%	0%	0%	2	21
16 Oct	0%	0%	0%	0%	0%	100%	0%	0%	3	37

DISCUSSION

Compared with the previous several years, subsistence sockeye harvest in Klawock Inlet was extremely low in 2005, but sockeye escapement into Klawock Lake remained steady at very close to the five-year average for 2001–2005 (Table 12). The overall number of sockeye salmon returning to Klawock Inlet was only about 15,000 in 2005, compared with 20,000 or more in 2001–2004. Thus, the reduction in the run size of about 5,000 fish came directly out of the subsistence harvest by the community, eliminating this source of food for most families in 2005 or leaving them to attempt to find subsistence fish elsewhere. We note that Klawock was not unique in 2005 in Southeast Alaska for having such a low subsistence sockeye harvest. Hydaburg residents, for example, harvested fewer than 1,000 sockeye salmon from several nearby runs, compared with typical harvests in recent years of over 5,000 fish (A. Christianson, Hydaburg Community Association, personal communication 2005). Although we don't know of any obvious reason for these low subsistence harvests, the very large run of pink salmon early in the 2005 season may have been a contributing factor. Early commercial fisheries openings, based upon pink abundance and timing, may have allowed more early returning sockeye salmon to be intercepted. Subsistence fishers found it difficult to catch sockeye salmon because of the large numbers of pink salmon in their nets, and perhaps the sockeye salmon stayed in deeper water underneath the schools of pink salmon (H. Kennedy, Klawock Cooperative Association, personal communication 2005). Interestingly, despite the very low subsistence sockeye harvest in July, more sockeye salmon than usual escaped into Klawock Lake in July. Because of the remarkably stable sockeye escapements between 2001 and 2005, we expect sockeye production from Klawock Lake to remain stable over the next several years and the harvest level to rebound.

Table 12.–Estimated subsistence harvest and escapement of sockeye salmon in the Klawock Lake system for 2001–2005. In all four years, subsistence harvest was estimated using on-site surveys in the Klawock Inlet fishery area. In all years, escapement was estimated by means of a weir and a mark-recapture study.

Year	Estimated subsistence harvest	95% confidence interval for subsistence harvest	Estimated escapement or weir count	95% confidence interval for escapement
2001	6,400	5,300–7,400	13,000	8,000–18,000
2002	6,000	5,300–6,800	12,600	11,500–15,100
2003	6,000	5,000–7,000	21,000	18,000–27,000
2004	4,500	3,800–5,100	12,400	12,000–14,000
2005	175	110–240	14,840	12,400–15,300
Mean	4,600		14,800	

Separate mark-recapture analyses of the sockeye spawning populations in the three main inlet streams in Klawock Lake in 2004 and 2005 confirmed that a substantial proportion of the fish counted at the weir could be estimated by these mark-recapture methods. In both years, the three stream-spawning populations totaled roughly 10,000 to 11,000 fish, which was about 70–75% of the weir-based estimate in each year. We expected the stream-based estimates to be somewhat lower than the weir-based estimates, because Klawock Lake has at least one other sockeye spawning stream (Hatchery Creek) not included in our estimates, and possibly other smaller spawning areas. Furthermore, we might expect some mortality between the time sockeye salmon entered the lake through the weir and arrived at their spawning streams several weeks later. Given the precision limits of the stream-based estimates, we could not conclude that any remaining difference with the weir-based estimates was meaningful. The Jolly-Seber model used for the stream-based estimates had more parameters and so was intrinsically less precise, but required fewer assumptions and so may have been more realistic. This method also allowed us to track individual fish, providing some information about timing and fish movement in the spawning streams. Recapture patterns seemed to confirm that residence times of sockeye spawners in the streams was very short, probably less than one week, and that very few live fish or carcasses remained in Threemile Creek beyond that length of time. As expected, very few fish moved between spawning areas during the spawning period. Besides providing valuable information for planning future mark-recapture sampling efforts, these results may have implications for sockeye spawning habitat in Klawock Lake. Short residence times suggest that sockeye spawners may be quickly flushed out of Threemile Creek, which could potentially affect spawning success. Availability of marine derived nutrients from salmon carcasses could also be altered if carcasses don't remain on the margins of the streams to decompose but are instead quickly washed back out into the lake (Hyatt et al. 2004). We have also visually observed heavy scouring and re-deposition of stream gravel in the spawning areas of Threemile Creek. Conducting mark-recapture sampling and surveys in Threemile, Inlet, and Halfmile Creeks in the future will provide valuable information over time about sockeye spawning populations and habitat use specific to each stream.

Because the harvest was so small in 2005, we did not observe the same degree of "cropping" on the early part of the run as we have in recent past years (Conitz et al. 2006). In fact, the first peak of escapement occurred between 23 July and 1 August in 2005, while the subsistence fishery was still open. As of 1 August, nearly 20% of the escapement had entered the lake, compared with only about 5% by the same date in 2004. The coincidence of unusually low subsistence sockeye harvest in July 2005 with a normal level of escapement was probably responsible for the larger early season escapement. We continue to recommend that fishery managers explore options for spreading the harvest over a longer period and allowing for greater early season escapement, in future years when harvest levels will hopefully rebound.

We noticed a continuation in a recent trend towards more sockeye salmon in the Klawock Lake escapement having two freshwater years. In fact, the percentage of age-2.2 sockeye salmon in the 2005 escapement was the highest observed, nearly 38%, a substantial increase from the previous year's high of 29% in 2004 (1982–2004; Appendix B in Cartwright and Conitz 2006; Conitz et al. 2006). In comparison, the percentage of age-1.3 fish from the same respective brood years, but which had only one year of freshwater growth, did not increase much from 2004 to 2005. If the age compositions in the escapement accurately reflect age compositions of smolt populations leaving Klawock Lake, the recent increase in fish smolting at two years could indicate some limitation on juvenile sockeye growth in the lake environment. However, we did not sample zooplankton or juvenile fish in Klawock Lake in 2005, so we have no other indicators of lake productivity. Resuming smolt sampling to estimate size and age composition would be a cost effective way to gauge lake productivity. The required sampling effort would be relatively inexpensive, and both measures are indicative of the ability of the lake to support sockeye fry growth (A. Mazumder, University of Victoria, personal communication 2006).

As noted in previous reports from this project (Lewis and Zadina 2001; Lewis and Cartwright 2002; Cartwright and Lewis 2004; Carwright and Conitz 2006; Conitz et al. 2006), we have some indications that historical runs were much larger than what we have observed in these recent years. Average annual escapements in the 1930s were at least twice as large as average escapements since 2001. Historical cannery records show even larger numbers of sockeye salmon processed by the Klawock canneries during their early years of operation. Not knowing the actual contribution of the Klawock sockeye stock to commercial harvests limits our understanding of true size or the dynamics of this stock over time. Genetic technology may, in the future, allow estimation of numbers of Klawock sockeye salmon in commercial catches.

Written records and anecdotal information seem to indicate the Klawock system has suffered some loss of productivity since at least the 1930s. Many years of clearcut logging throughout the watershed, as well as road and highway construction and municipal water removal from Halfmile Creek, have obviously degraded habitat and probably reduced the physical space available for sockeye spawning and rearing in the system. As noted above, we recommend continuing mark-recapture studies and surveys in the spawning streams, to provide some measure of habitat availability and suitability over time. Food limitation in the lake rearing habitat may also be curtailing sockeye production, as evidenced by the apparent increase in average age of smolting. Increasing hatchery output since the mid 1980s, of up to five million juvenile sockeye and coho fry annually, contrasts with a decline in juvenile sockeye growth in terms of smolt age, and in desirable zooplankton prey populations (A. Mazumder, University of Victoria, unpublished report 2006). We agree with Mazumder's recommendation to lower the hatchery fry output for several years and monitor for changes in measures of productivity such as zooplankton composition and abundance and smolt age and size. If the total fry population in the lake, including hatchery fry, is already too large for the available food resources, increasing the escapement would likely not have the desired effect of increasing sockeye production overall. Without knowing why sockeye salmon populations have decreased in Klawock Lake, and without any sure methods to increase production, we at least recommend attempting to maintain a level of escapement similar to the average level in 2001–2005. Judging from past indications, this level of escapement should allow a stable annual subsistence harvest of around 6,000 sockeye salmon (Conitz et al. 2006).

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ACKNOWLEDGMENTS

The authors acknowledge the assistance of many people for help with project design, fieldwork, data analysis, and reporting. The Klawock Cooperative Association (KCA) continued to be an excellent partner in the project, with Cheryl Griffits providing administrative support and crew members Henry Kennedy and Peter Brown conducting most of the actual field sampling. Susan Domenowske was hired as the ADF&G field biologist for the Klawock and Hetta sockeye projects in July 2005 and quickly learned the essential duties for these projects. She also assumed the role of acting field crew leader for the Klawock sockeye project, because we were unable to fill that position in 2005. James Rowan filled a temporary technician position with ADF&G during the second half of the season, and the entire crew was grateful for his hard work and competence. We thank John Bruns, hatchery manager for the Prince of Wales Hatchery, his assistant Karen Robinette, and other members of his crew for help in construction of the weir trap, and for working cooperatively with our project crew on weir operations and data collection. As always, we depended upon Iris Frank, Mark Olsen, and other members of the ADF&G salmon aging lab for analyzing and compiling the sockeye age, sex, and length data. Renate Riffe, biologist with ADF&G, analyzed the subsistence harvest data. Hal Geiger, ADF&G salmon research supervisor, provided leadership and helpful reviews of operation plans, statistical design and analysis, and reports. We also thank Leon Shaul, a salmon fisheries biologist with ADF&G, for his insightful review comments.

APPENDIX A

Appendix A.–Daily and cumulative sockeye counts and daily number tagged at the Klawock River weir in 2005; daily counts, by species, of other salmonids entering Klawock Lake through the weir; daily water temperature and depth at the weir.

			Sockeye salmon			Daily counts, other species			
Date	Water depth (m)	Water temp (^oC)	Daily count	Cumulative count	Number tagged	Coho	Pink	Chum	Dolly Varden
5-Jul	-	-	0	0	-	0	0	0	0
6-Jul	-	-	0	0	-	0	0	0	0
7-Jul	-	-	0	0	-	0	0	0	0
8-Jul	1.07	13.0	14	14	0	0	0	0	2
9-Jul	0.99	13.0	22	36	0	0	0	0	8
10-Jul	1.12	13.0	9	45	0	0	0	0	44
11-Jul	1.12	13.0	38	83	18	2	0	0	0
12-Jul	1.04	16.5	11	94	0	2	0	0	1
13-Jul	0.99	12.0	4	98	0	1	0	0	0
14-Jul	0.94	-	4	102	0	1	0	0	0
15-Jul	1.14	-	13	115	0	4	0	0	22
16-Jul	1.14	12.0	23	138	17	5	6	0	7
17-Jul	1.07	-	7	145	0	2	1	0	1
18-Jul	0.99	17.0	1	146	0	10	143	0	8
19-Jul	1.09	17.0	7	153	0	1	410	0	13
20-Jul	1.07	17.0	3	156	1	1	111	0	4
21-Jul	0.97	17.0	7	163	0	0	445	0	10
22-Jul	0.94	17.5	17	180	7	1	376	0	7
23-Jul	0.91	16.0	184	364	0	0	1,560	0	5
24-Jul	1.07	-	16	380	0	11	801	0	4
25-Jul	1.00	17.0	36	416	0	8	946	0	2
26-Jul	0.95	18.0	338	754	0	8	4,671	2	3
27-Jul	0.95	18.0	321	1,075	91	4	4,241	1	3
28-Jul	1.02	18.0	329	1,404	0	3	5,526	0	4
29-Jul	0.99	18.0	151	1,555	0	3	5,688	0	5
30-Jul	0.97	18.5	164	1,719	19	1	4,586	0	0
31-Jul	1.04	-	788	2,507	0	3	6,346	0	0
1-Aug	1.09	18.0	210	2,717	84	36	3,845	4	5
2-Aug	1.07	16.0	61	2,778	23	18	5,730	0	5
3-Aug	1.02	19.0	145	2,923	37	0	2,862	0	6
4-Aug	1.00	18.0	152	3,075	40	1	1,640	0	1
5-Aug	1.02	18.0	108	3,183	0	2	1,444	0	3
6-Aug	1.04	-	240	3,423	14	0	2,120	0	1
7-Aug	1.09	-	270	3,693	0	1	4,001	0	1
8-Aug	1.04	17.0	76	3,769	22	44	2,348	12	4
9-Aug	0.99	17.0	109	3,878	110	34	506	2	4
10-Aug	0.94	18.0	121	3,999	120	23	1,052	15	7
11-Aug	0.89	18.0	248	4,247	243	4	777	0	5
12-Aug	0.85	18.0	132	4,379	77	3	1,242	16	36
13-Aug	0.81	18.0	257	4,636	126	3	1,164	7	11
14-Aug	0.79	-	632	5,268	0	6	2,393	8	9
15-Aug	0.79	19.0	472	5,740	291	33	1,579	7	1

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			Sockeye Salmon			Daily Counts, other species			
Date	**Water depth (m)**	**Water temp (°C)**	**Daily count**	**Cumulative count**	**Number tagged**	**Coho**	**Pink**	**Chum**	**Dolly Varden**
16-Aug	0.76	19.0	748	6,488	147	67	3,066	9	9
17-Aug	0.76	19.0	579	7,067	96	10	4,484	4	23
18-Aug	0.76	19.0	373	7,440	0	4	3,637	26	34
19-Aug	0.91	19.0	703	8,143	192	6	7,286	34	25
20-Aug	1.09	19.0	121	8,264	0	1	9,639	2	0
21-Aug	1.07	18.0	61	8,325	9	3	7,625	3	0
22-Aug	1.19	18.5	247	8,572	0	136	10,106	11	0
23-Aug	1.22	18.0	190	8,762	41	66	8,817	6	0
24-Aug	1.09	18.0	91	8,853	0	18	4,647	1	0
25-Aug	0.99	19.0	196	9,049	49	16	4,366	0	3
26-Aug	1.22	18.0	409	9,458	0	17	7,017	6	3
27-Aug	1.17	19.0	113	9,571	0	7	7,124	1	0
28-Aug	1.14	-	163	9,734	0	19	4,887	0	0
29-Aug	1.07	18.0	172	9,906	111	181	1,282	2	3
30-Aug	0.89	18.0	321	10,227	42	14	3,634	1	2
31-Aug	1.12	17.5	188	10,415	65	13	2,233	0	0
1-Sep	1.12	17.0	77	10,492	31	11	493	1	4
2-Sep	1.07	17.0	257	10,749	22	13	3,958	3	0
3-Sep	0.97	17.0	178	10,927	0	29	1,587	1	3
4-Sep	0.99	-	216	11,143	0	11	1,490	1	0
5-Sep	0.91	17.0	118	11,261	41	212	1,428	1	2
6-Sep	0.91	17.0	285	11,546	86	53	1,255	3	3
7-Sep	1.07	17.0	598	12,144	75	39	3,590	1	0
8-Sep	1.35	16.5	211	12,355	39	29	4,315	0	0
9-Sep	1.24	15.0	153	12,508	29	34	4,751	1	0
10-Sep	1.14	16.0	84	12,592	0	52	685	0	0
11-Sep	1.07	-	40	12,632	0	0	229	1	0
12-Sep	0.99	15.0	223	12,855	52	310	2,865	5	0
13-Sep	0.99	16.0	125	12,980	0	28	520	1	0
14-Sep	0.99	15.0	250	13,230	0	48	495	1	0
15-Sep	0.97	15.0	163	13,393	0	30	394	1	0
16-Sep	0.91	15.0	123	13,516	0	28	809	1	0
17-Sep	0.89	-	166	13,682	0	26	859	0	0
18-Sep	1.30	-	512	14,194	0	75	3,840	1	0
19-Sep	1.55	15.0	77	14,271	0	446	4,034	1	0
20-Sep	1.50	15.0	35	14,306	0	125	528	1	0
21-Sep	1.35	15.0	59	14,365	0	49	426	0	0
22-Sep	1.22	15.0	31	14,396	0	72	452	0	0
23-Sep	1.09	15.0	89	14,485	0	69	1,251	0	0
24-Sep	1.27	-	39	14,524	0	97	81	0	0
25-Sep	1.37	-	36	14,560	0	81	247	0	0
26-Sep	1.24	14.0	34	14,594	0	438	82	0	0
27-Sep	1.45	14.0	15	14,609	0	21	64	0	0
28-Sep	1.56	14.0	82	14,691	0	98	223	2	0
29-Sep	1.80	14.0	25	14,716	0	65	324	0	0
30-Sep	1.78	13.5	16	14,732	0	80	28	0	0

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Appendix A.–Page 3 of 3.

Date	Water depth (m)	Water temp (°C)	Sockeye Salmon Daily count	Sockeye Salmon Cumulative count	Sockeye Salmon Number tagged	Daily counts, other species Coho	Pink	Chum	Dolly Varden
1-Oct	1.55	-	7	14,739	0	25	6	0	1
2-Oct	1.37	-	4	14,743	0	78	49	0	2
3-Oct	1.17	13.0	2	14,745	0	107	60	0	0
4-Oct	1.09	13.0	7	14,752	0	222	8	0	0
5-Oct	1.04	13.0	0	14,752	0	44	22	0	2
6-Oct	1.14	12.0	1	14,753	0	54	8	0	0
7-Oct	1.12	12.0	2	14,755	0	11	10	0	0
8-Oct	-	-	5	14,760	0	27	2	0	0
9-Oct	1.09	-	8	14,768	0	10	8	0	8
10-Oct	1.30	11.0	1	14,769	0	44	14	0	0
11-Oct	1.30	-	20	14,789	0	216	2	0	0
12-Oct	1.63	-	1	14,790	0	207	15	0	1
13-Oct	1.52	-	0	14,790	0	15	4	0	4
14-Oct	1.31	-	2	14,792	0	20	4	0	3
15-Oct	1.37	-	5	14,797	0	7	1	0	3
16-Oct	1.14	-	10	14,807	0	9	3	0	0
17-Oct	1.56	9.0	3	14,810	0	10	0	0	2
18-Oct	1.40	10.0	1	14,811	0	263	1	0	0
19-Oct	1.24	9.0	0	14,811	0	1	0	0	2
20-Oct	1.14	9.0	0	14,811	0	4	0	0	0
21-Oct	1.17	9.0	7	14,818	0	8	4	0	1
22-Oct	1.35	-	1	14,819	0	7	0	0	4
23-Oct	1.37	-	3	14,822	0	9	0	0	0
24-Oct	1.37	9.0	0	14,822	0	55	0	0	0
25-Oct	1.27	8.0	3	14,825	0	109	1	0	1
26-Oct	1.27	8.0	2	14,827	0	59	0	0	1
27-Oct	1.17	8.0	0	14,827	0	3	0	0	0
28-Oct	1.09	8.0	2	14,829	0	4	0	0	5
29-Oct	1.04	-	0	14,829	0	0	0	0	0
30-Oct	1.17	-	0	14,829	0	0	0	0	0
31-Oct	1.12	8.0	6	14,835	0	137	0	0	1
1-Nov	1.16	8.0	2	14,837	0	213	0	0	20
2-Nov	-	-	0	14,837	0	0	0	0	0
3-Nov	1.09	8.0	3	14,840	0	78	0	0	0
4-Nov	1.07	7.0	0	14,840	0	329	0	0	0